HYDROGRAPHIC AND TIDAL INFORMATION FOR DEEP DRAUGHT SHIPS IN A TIDAL ESTUARY

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SUMMARY

The principal oil refineries in the Port of London are situated at Thameshaven and Coryton, over 50 miles from the true entrance to the port at Long Sand Head. Here deep draught tankers first enter areas where charted depths are less than their draught and so require the tide to give sufficient water to navigate. This 50 mile passage is through a complex estuary, where drying sandbanks alternate with deeps; and where two tidal systems (that from the North Sea and that from the Straits of Dover) meet and interact with resultant instability of the sea bed in certain areas; some 12 miles of this passage are dredged.

To bring into the Port ships drawing up to 48 feet (100 000 ton tankers fully laden and 200 000 ton tankers part laden) with an underkeel clearance of only 3 - 4 feet requires great skill on the part of the Master and Pilot and this skill must have a sound basis of up-to-date data. They must have accurate hydrographic surveys and actual tidal heights, as well as comprehensive tidal predictions to enable them to plan and execute the passage with safety.

This paper discusses the hydrographic surveys required for this purpose in terms of accuracy of measured depth, tidal reduction of soundings, and accuracy of position fixing and how this is applied in the Port of London. It also describes the tidal predictions used, and how, by means of radio-linked tide gauges and the port's communication system actual tidal information is passed to the ships. The means of interpreting this information co-tidally along the 50 mile passage is also described. The paper then briefly discusses future requirements in this field.

1. INTRODUCTION

Fom the point of view of a ship coming to the Port of London the Thames Estuary starts at the North Foreland in the South and the Sunk in the North and extends to the ship's berth which may be at the oil jetties of Thameshaven, the container port at Tilbury or riverside berths and enclosed docks further up the river. The distance steamed could be from 30 to 80 miles through the complex outer estuarial area (illustrated in figure 1) and the inner riverine estuary.

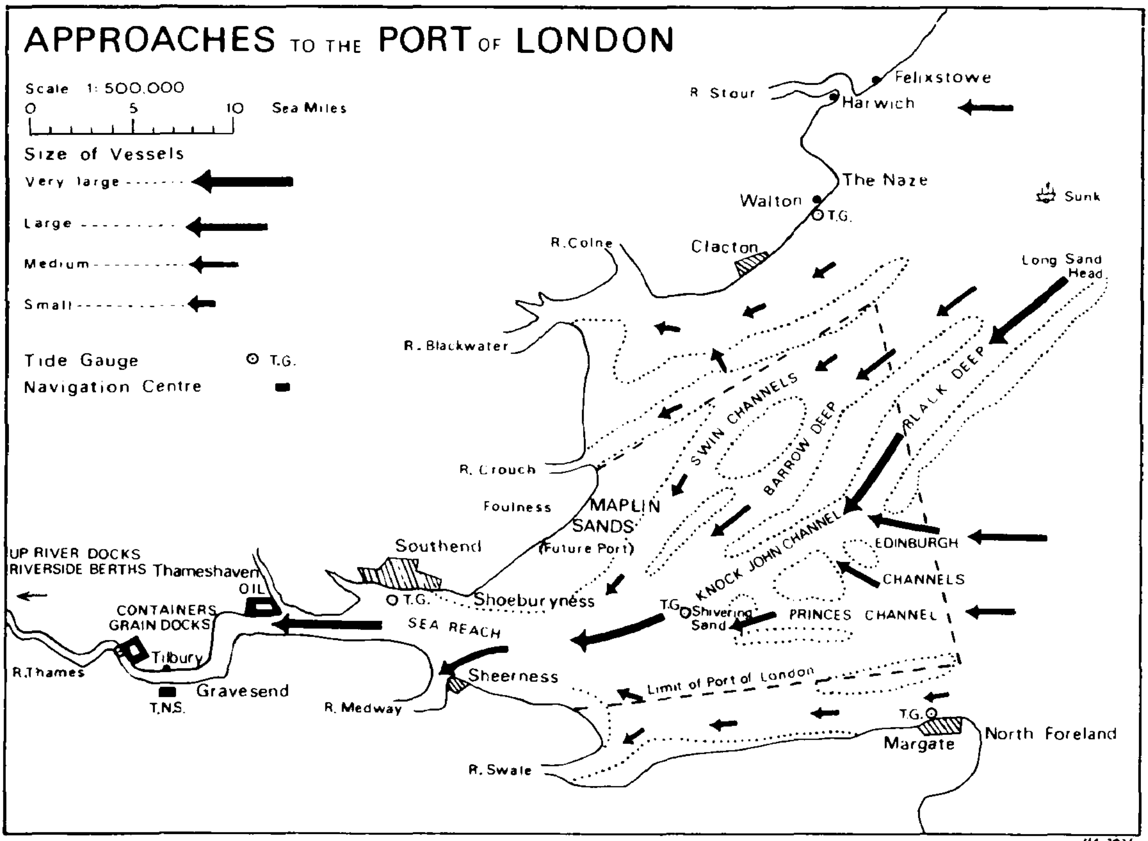

Fig. 1.

In this paper we will consider the most difficult problem posed by this estuary, that of getting the largest vessels from sea to the refineries in the Thameshaven area. These ships, tankers of 115 000 tons fully laden and 230 000 tons part laden normally draw about 45 feet (13.7 metres); the deepest that has come to the Port drew just under 49 feet (15 metres); the largest are 1100 feet (335 m) overall by 160 feet (49 m) beam : their entry route is through the Black Deep, the Knock John and Sea Reach dredged channels to Thameshaven — a distance of 50 nautical miles. The depth at the start of their passage is 42 feet (12.8 m) below datum reducing to 31½ feet (9.6 m) off the berths, so the vessels have to come in with the flood tide.

2. WHAT DEPTH OF WATER IS REQUIRED?

The depth of water required by a ship on passage is the still water draught of the vessel plus an allowance for Under Keel Clearance. This passage depth, as we shall call it, is the charted depth at a point (referred to local chart datum which is Lowest Astronomical Tide in the Thames Estuary) plus the tidal height above datum at the instant of passing a point.

It is beyond the scope of this paper to discuss Under Keel Clearance in detail but one must have some idea of its magnitude when considering the passage of large vessels. Underkeel clearance can be defined as the difference between the vessel's draught (when the ship is stopped and in water of the general ambient specific gravity) and the passage depth defined above.

Thus it must allow for :

(a) Increase of draught due to hydrodynamic effects (squat, roll, pitch, heave) [1].
(b) Any inaccuracy of charted depth.
(c) Any inaccuracy of tidal height.
(d) Any inaccuracy in ship's draught.

In the Port of London ships generally come into the Port with about 3 to 4 feet (1 metre) underkeel clearance in the shoal areas. It should be noted that this refers to a rising tide, but nonetheless it points to a high accuracy requirement in assessing the factors listed above, not to say skill on the part of Master and Pilot in handling the ship and keeping not only to the correct geographical track but also to the time schedule dictated by the tide.

Having decided the draught of ship and underkeel clearance required, the passage depth is thus established. The design depths of the approach channel can then be found by using a Ship Passage Diagram (see figure 2) [2]. This shows in Section (A) — Time, the passage of the ship from sea to the berth in terms of time, measured relative to the time of high water at the berth. Before drawing this graph one has first to determine the optimum time of arrival at the berth and the speeds that the vessel will make on the various stages of the passage. In this case we are considering a 200 000 ton tanker arriving in the berth 15 minutes before local high water at speeds over the ground reducing from 12 knots in the outer approaches to 9½ knots in Sea Reach, an average passage for this class of vessel. From this information, the local tidal heights along the ship's passage can be deduced — here a typical mean neap tide has been used. The increase of high water height as one progresses into the estuary is also shown in this section; the graph of tidal height against distance is shown in Section (B) — Tide. Section (C) — Depth shows the resultant depth below

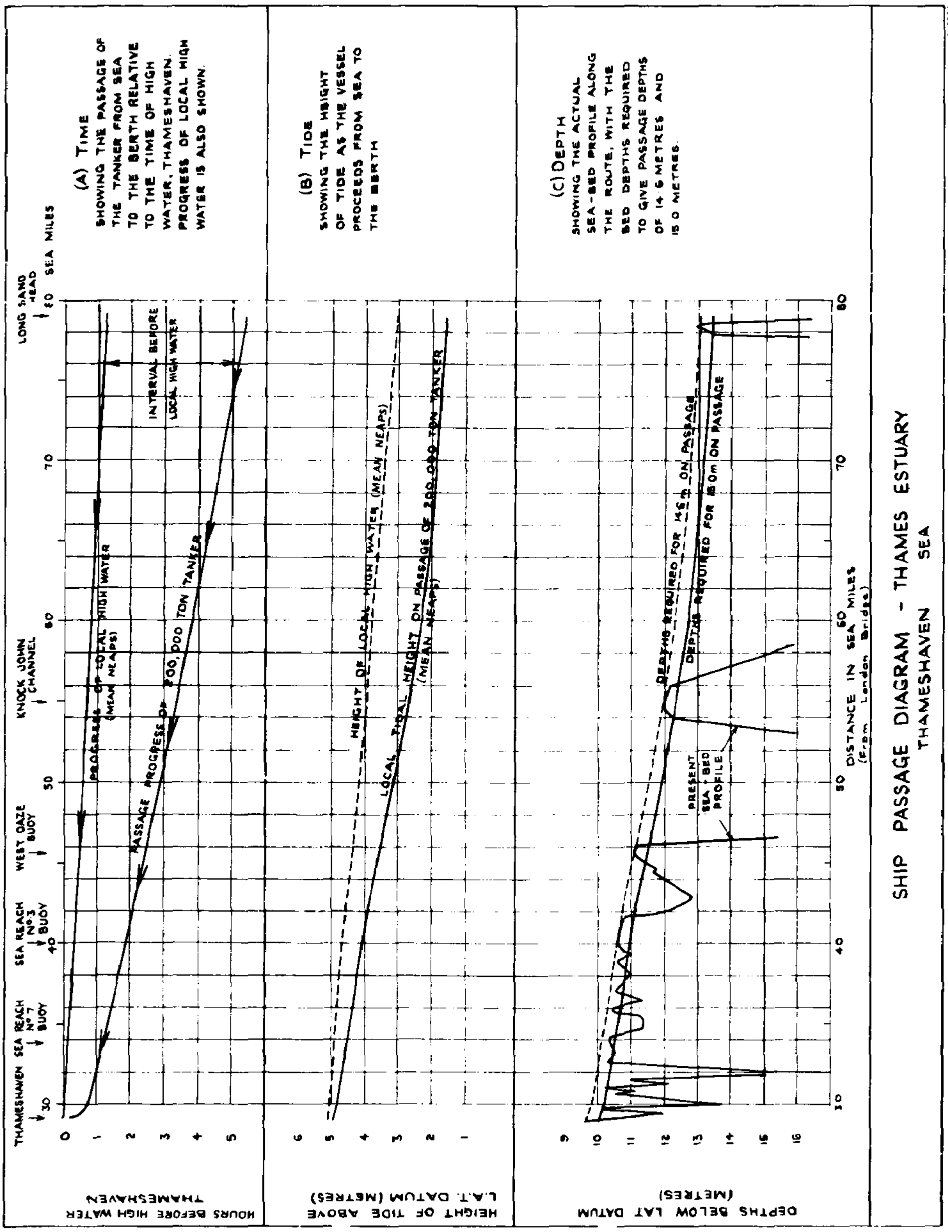
SHIP PASSAGE DIAGRAM - THAMES ESTUARY
THAMESHAVEN SEA
(A) TIME
SHOWING THE PASSAGE OF THE TANKER FROM SEA TO THE BERTH RELATIVE TO THE TIME OF HIGH WATER, THAMESHAVEN. PROGRESS OF LOCAL HIGH WATER IS ALSO SHOWN.
(B) TIDE
SHOWING THE HEIGHT OF TIDE AS THE VESSEL PROCEEDS FROM SEA TO THE BERTH
(C) DEPTH
SHOWING THE ACTUAL SEA-BED PROFILE ALONG THE ROUTE, WITH THE BED DEPTHS REQUIRED TO GIVE PASSAGE DEPTHS OF 14·6 METRES AND 15·0 METRES.
HOURS BEFORE HIGH WATER THAMESHAVEN
HEIGHT OF TIDE ABOVE L.A.T. DATUM (METRES)
DEPTHS BELOW LAT DATUM (METRES)
DISTANCE IN SEA MILES (From London Bridge)
THAMESHAVEN
SEA REACH Nº 7 BUOY
SEA REACH Nº 3 BUOY
WEST OAZE BUOY
KNOCK JOHN CHANNEL
LONG SAND HEAD
SEA MILES
PROGRESS OF LOCAL HIGH WATER (MEAN NEAPS)
PASSAGE PROGRESS OF 200,000 TON TANKER
INTERVAL BEFORE LOCAL HIGH WATER
HEIGHT OF LOCAL HIGH WATER (MEAN NEAPS)
LOCAL TIDAL HEIGHT ON PASSAGE OF 200,000 TON TANKER (MEAN NEAPS)
DEPTHS REQUIRED FOR 14·6m ON PASSAGE
DEPTHS REQUIRED FOR 15·0m ON PASSAGE
PRESENT SEA-BED PROFILE

FIG. 2.

datum needed to give the passage depth required : this is simply the passage depth minus the local tidal height from (B).

Section (C) also shows the existing bed profile and the sea bed depths required to give both 48 feet (14.6 m) and 49.2 feet (15.0 m) on passage. It will be seen that the existing depths will allow a ship to berth at Thameshaven 15 minutes before local high water on mean neap tides and to carry a depth of 48 feet (14.6 m) from sea to the berth.

To increase this depth by just over one foot (0.4 m) would mean dredging the sea bed area lying between the two lines. The cost of doing this work would be of the order of £1 000 000 so the case for providing accurate hydrographic surveys and tidal information rather than increasing underkeel clearance by dredging has sound economic backing.

The Ship Passage Diagram considered covers one particular set of circumstances, namely a 200 000 ton tanker arriving at the berth just before High Water at mean neap tides and proceeding at certain speeds, and the channel is designed to those particular circumstances. Some ships on some occasions will not meet those conditions — the ship may be too deep draughted for the tide, or not capable of making the speed required from some extraneous cause such as fog — in which case entry is made to the port by 'staging' the passage, that is the ship anchors over the ebb tide and low water period in one of the deep water anchorages and proceeds to the berth on the next, or subsequent, tide.

3. HYDROGRAPHIC SURVEYS

The Port of London Authority maintains a hydrographic service whose area of responsibility covers the Thames estuary from Teddington to the outer Port Limits (see figure 1). The estuary is divided into survey areas which are surveyed at the frequency and on the scale necessitated by their usage, stability and significance. Thus the Knock John and Sea Reach Channels are surveyed at 2-month intervals, whilst the Barrow Deep is surveyed every three years and other more significant areas are surveyed either 6 monthly or annually. Less important areas wait up to nine years before resurvey.

Accuracy requirements of a position fix

The surveyor's requirement is that a position fix must be accurate on the scale on which he is plotting his survey. It is not easy to define this requirement numerically but it could be said that the Standard Deviation of a fix should not exceed a certain maximum plottable increment on the scale of the survey : if this increment were 1/2 millimetre, then for coastal surveys on a scale of 1/25 000 the Standard Deviation of a fix would be 12½ metres. This is the scale used for most surveys in the outer part of the Thames estuary, but in the dredged channels and other critical areas surveys are made on a much larger scale (1/2 500 or 1/5 000) and the proportional fixing accuracies (of 1¼ and 2½ metres respectively) are difficult to attain.

Decca Hi-Fix, in the hyperbolic mode, is used for position fixing by the Port of London Authority; the dredged channels and other critical areas are in general within the theoretical 3-metre repeatability accuracy contour of the chains for a Standard Deviation of 1/100th of a lane. For the same areas, calibration checks carried out indicate that the Standard Deviation of a fix is likely to be 3/100ths of a lane in terms of absolute accuracy (as distinct from repeatability) if monitor corrections are applied from some point within the coverage : 3/100ths lane will be equivalent to about 9 metres within this area.

Thus the Port of London Authority finds itself with a fixing system having an accuracy of say ± 10 metres, but apparently needing to fix with an accuracy 4 times better than this. In fact the repeatability accuracy of Hi-Fix is sufficient to ensure that closely spaced sounding lines are accurately positioned relative to one another, and thus that the survey area is being systematically covered. That the eventual plotted position of a shoal sounding is incorrect by say 10 metres is not of great importance; the dredger that comes to dredge it will be using the Hi-Fix and the 200 000 ton tanker will either treat that shoal depth as the ruling depth in the channel or ensure that it can be avoided by a margin far larger than 10 metres.

In practice, then, Hi-Fix with its probable repeatability accuracy of better than 5 metres and absolute accuracy of 10 metres is used for sounding on scales of between 1/2 500 and 1/25 000 in the outer Thames Estuary. It is normal practice for the surveyors to check the Hi-Fix against sextant fixes whenever these are obtainable, and the Estuary chain is continuously monitored from a receiver at Sheerness. Calibration checks are still being made, particularly in the fringe areas.

Accuracy of Sounding

The accuracy of a sounding, given that the position fix is correct, is a combination of the accuracies of the depth measurement and of the tidal reduction.

It is standard practice in the Port of London Authority to bar check the echo sounder before commencing and after completing the day's work; the echo sounder transmission setting and stylus speed are checked from time to time throughout the day. A depth read off the echo sounder trace should be accurate to within 3 inches (one decimetre).

With tidal reductions, the aim is to apply corrections in such a manner that the tidal reduction is correct to within 3 inches (one decimetre). There are difficulties in achieving this; tidal propagation in the Thames Estuary is complex and, whilst very useful co-tidal charts (in terms of high and low water time differences and range, for mean spring and mean neap tides) have been drawn up by the Hydrographic Department of the Royal Navy, these are really a consensus derived from comprehensive past observations, and errors can occur when they are used for individual tides. This particularly applies at times between high and low water, since the data on which they are based can take no account of the shape of the tidal curve in different parts of the estuary. Nometheless the co-tidal charts can be used with confidence in transferring tidal heights over short distances in settled meteorological conditions. There is no doubt that the most accurate means of obtaining tidal reductions is to use a tide gauge very close to the area being sounded.

The Port of London Authority operates a number of permanently installed float-operated automatic recording tide gauges in the Thames Estuary, five of which (at Walton, Margate, Shivering Sands, Southend and Tilbury) are linked by UHF telemetry to remote recorders situated in the Thames Navigation Centre at Gravesend (see figure 1) [3]. For most purposes the tidal height at any point at any instant can be deduced by using gauges in conjunction with the co-tidal charts, preferably using two gauges as a cross check. However, when greater precision is required portable gauges or tide boards can be placed on navigational beacons near the survey area to augment the permanent gauges; these of course are not radio linked and their installation and maintenance is time consuming, and we have yet to find a truly portable, reliable and accurate recording gauge for this purpose.

The other factor closely affecting sounding accuracy is the motion of the craft in a seaway; there is at present only one way of reducing errors due to this, and that is to survey only when the sea is sufficiently calm. In the future it may well be possible to remove some of the ship-motion from the echo-sounder record electronically [4], enabling work to be continued in worse conditions than is possible at present.

4. DISSEMINATION OF INFORMATION TO SHIPPING

There are two classes of information to be disseminated; long and medium term as represented by the hydrographic surveys and tidal predictions, and short term as represented by actual tidal heights and immediate hydrographic information, such as the existence of shoals or wrecks.

Long and medium term information

The long term hydrographic information is published by the Hydrographer of the Navy as Admiralty Charts, using the Port of London Authority surveys as the basis for correction. The Port of London Authority also publishes charts of the inner estuary; copies of all surveys (which can be considered medium term) are sent to the Pilot stations at Folkestone, Harwich and Gravesend so that the Trinity House Pilots are appraised of the latest situation regarding depths in the dredged channels and approaches generally.

Tidal predictions of the times and heights of high and low water at Walton, Margate, Sheerness and London Bridge are also published in the Admiralty Tide Tables; these are also published in the Port of London Authority's own tide tables, with Southend replacing Sheerness, together with predictions for Tilbury and North Woolwich. In addition, the Port of London Authority publishes hourly height predictions for Walton, Margate, Southend, Tilbury and North Woolwich : Shivering Sands will be added in 1972. The tables are prepared by the Institute of Coastal Oceanography and Tides, who also carry out the harmonic analyses on which the predictions are based.

Short term information

The Thames Navigation Service, situated at Gravesend, makes routine broadcasts to shipping each half-hour on International VHF channels : these broadcasts contain general information for shipping and include any specific hydrographic information in the form of serially numbered P.L.A. Navigational Warnings; the latter are also sent to the Pilot stations by Telex.

The half hourly broadcasts also include the tidal height at Southend as read from the radio linked gauge. The display of this gauge is an ordinary graph recorder (see figure 3) on which the predicted tide curve is drawn; the broadcast can thus include reference to any marked divergence of the actual tide from the predicted tide. Tidal information from the other gauges (Margate, Walton, Shivering Sands and Tilbury) is passed to shipping on demand.

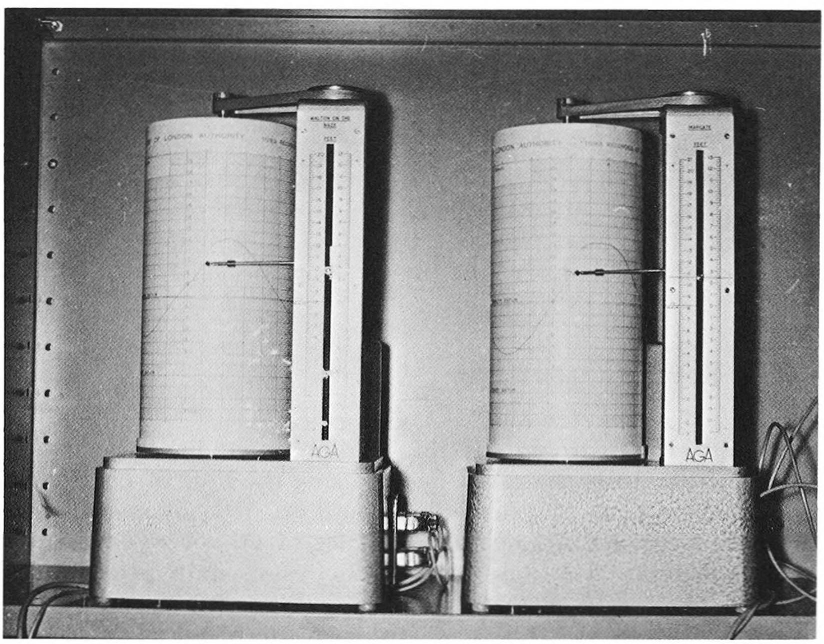

Fig. 3. — Remote Tide Recorders at the Thames Navigation Centre, Gravesend.

5. INTERPRETATION OF THE HYDROGRAPHIC AND TIDAL INFORMATION

From the point of view of the Master and Pilot of a deep draughted tanker coming into the Port there are a very large number of questions to be asked, answers obtained and decisions taken. A number of these are beyond the scope of this paper (Is the visibility good enough ? Is the berth ready ? What other ships are there in the Channel ? are examples), but the principal questions from the hydrographic point of view are :

(a) What are the critical depths in the channel, at chart datum ?
(b) At what points along the track do these critical depths occur ?
(c) At what times will the tidal heights at these points be sufficient to give the ship the passage depth which is required ?
(d) What are the latest times along the route that the passage depths are available ?

The first two questions can be answered from the sounding surveys which are available to the Pilot before he boards at the Pilot Station. The point along the route is defined in sea miles from London Bridge — a somewhat false datum point for the largest vessel but a convenient one for general purposes since but few seagoing vessels proceed above the bridge. The third question can be answered by using the tide tables in conjunction with the co-tidal charts and this is the method largely used at present for the majority of vessels where small underkeel clearances are not necessary and only occur at one or two points along the passage. Thus a vessel might require to know the time that the passage depth is available in the Edinburgh Channels, at Sea Reach No. 7 buoy and in Gravesend Reach. Where underkeel clearances are small and affect a larger proportion of the passage, then the number of such calculations makes this process cumbersome, and some useful conversion tables have been compiled by Pilots to ease this problem.

Passage Planning Diagrams

With the number of 100 000 ton tankers coming to the Port increasing and with the onset of the 200 000 ton tanker it became apparent that the existing methods did not meet present needs. It was now necessary to be able to pre-plan the tanker's passage according to the predicted tides and to amend this planned passage in the light of the actual tides which developed as the passage proceeds.

A promising way of achieving this was at first thought to be the production of an inversion of the Ship Passage Diagram (described in Section 2) in which the sea bed profile would be drawn and to which the tidal profile could be added. After discussion with the Pilots and ship owners concerned the Passage Planning Diagram (figure 4) (*) was produced.

(*) Ed. note : In the reduced version reproduced herewith, only a general idea is provided; readers desiring to follow a specific analysis in detail should address a request to the author for a full-size example for study.

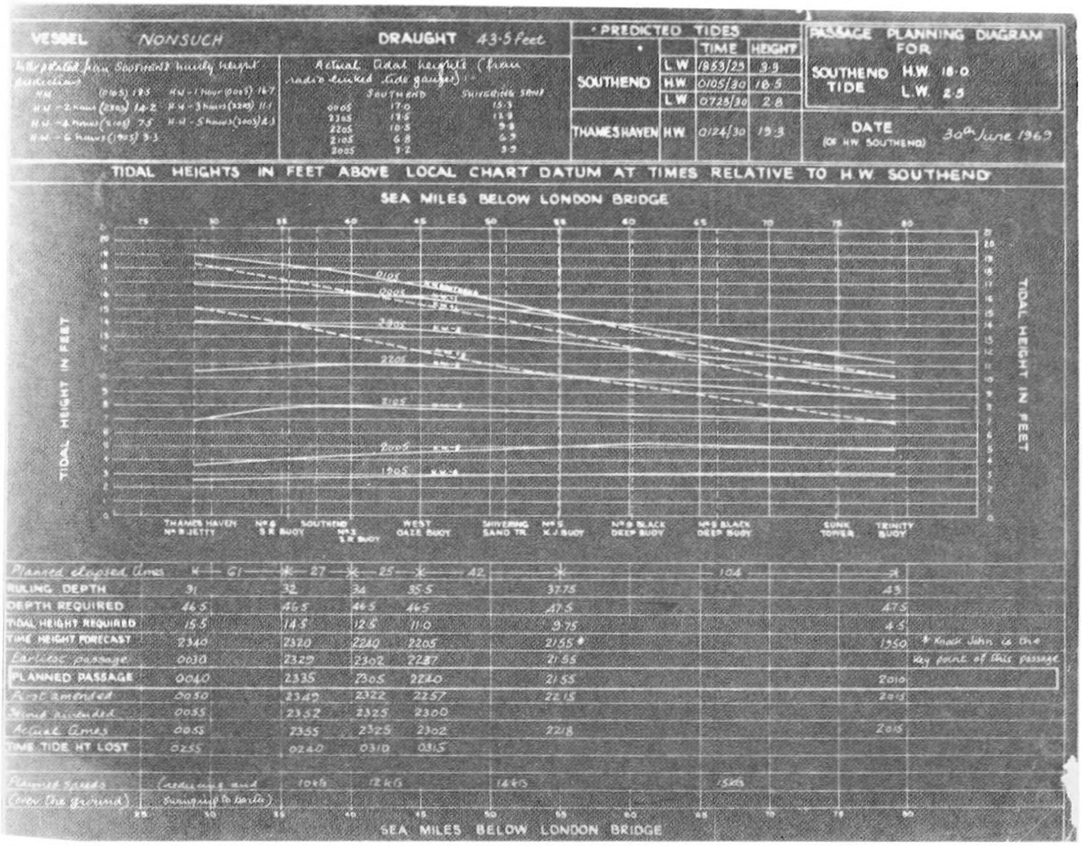

Fig. 4.

This consists, essentially, of three parts. The top part has space for entering the details of the ship, the tidal predictions and any other notes the Pilot or Master may wish to make. The second, middle, portion consists on a 'tidal surface diagram' showing the height of the tide at hourly intervals along the passage from Thameshaven to the Trinity Buoy (in the Sunk/ Long Sand Head vicinity — see figure 1). The times are referred to High Water, Southend — the tidal station for which tidal heights are broadcast, and extend from 6 hours before to 2 hours after High Water there. The third, lower, part of the diagram is a tabulation of the depths, tidal heights and times along the passage. The Pilot can enter depths at chart datum for the critical points (obtained from the latest surveys), the passage depth required (draught plus underkeel clearance) and hence the tidal height at each critical point to give this passage depth. The times at which the required tidal height is attained at each critical point can be interpolated from the Tidal Surface Diagram and entered into the Tabular part of the form. Then, from the expected performance of the vessel, the Pilot can deduce the earliest possible passage and making any allowances for delays etc. can list his Planned Passage Times. He can also enter the times at which he loses the tide for the latter part of the passage.

The limitation of this method of passage planning is the small number of different tides that can conveniently be expressed in this form and still give the prediction accuracy that is required (within about 6 inches or 2 decimetres in good conditions). To cover all tides at Southend, as defined by their high and low water height would require some 80 versions of the tidal surface diagrams if the high and low water heights were considered in 6-inch steps.

It was decided that it was not practicable to produce more than 8 different Passage Planning Diagrams and tidal surface diagrams were therefore produced for tides having the following High and Low Water heights at Southend (heights in feet) :

High Water	19.0	19.0	18.0	18.0	17.0	16.0	15.0	14.0
Low Water	1.0	2.0	2.5	4.0	3.5	4.5	5.5	6.0

This limitation can be partly overcome by using the hourly height predictions for Southend to test the validity of the tidal surface diagram in use for a particular passage : the times at which heights of integral feet are attained are interpolated from the hourly height tables and these times marked on the tidal surface diagram where they can be compared with the individual graphs at hourly intervals. This can be done before the ship approaches the outer estuary; as the passage develops actual tidal heights from the gauges can be obtained by VHF radio and the passage times amended to accord with the actual tide.

Some of these difficulties could be overcome by presenting the tide predictions along the route in graphical form on a daily basis (or in continuous roll form) as shown in figure 5 a. Here the vertical axis shows time (in terms of British Standard Time) and the horizontal axis shows distance in sea miles (again measured from London Bridge); the contours are lines of equal (predicted) tidal height, whilst the occurrence of high and low water is shown by the slightly sloping dashed and dotted line with the times and heights marked on it at the tidal stations. This diagram could be based on the predictions at Tilbury, Southend, Shivering Sands and Walton, with intermediate points interpolated, using the co-tidal charts to provide the interpolation coefficients : the method could be handled by a computer and the diagram be plotted by a drum plotter. Alternatively, the presentation could be in the form of a numerical print out from the computer as shown in figure 5 b. Both of these presentations are being investigated by the Institute of Coastal Oceanography and Tides.

It is thought that this proposed tidal prediction diagram will be simpler to use in practice than the present Passage Planning Diagram. The presentation is clear and as accurate as are the predictions; the only correction required is for the difference between the predicted and actual tides. The passage information can be drawn on the diagram and a separate Passage Planning form completed if required.

The divergencies between predicted and actual tides can be significant and are sometimes considerable. In settled weather conditions one can expect the predictions to be within 6 inches in height and 10 minutes in time from the actual tide. However, weather conditions severely affect tidal propagation in the southern North Sea and storm surges of several hours' duration and several feet in amplitude can raise the tide to about 8

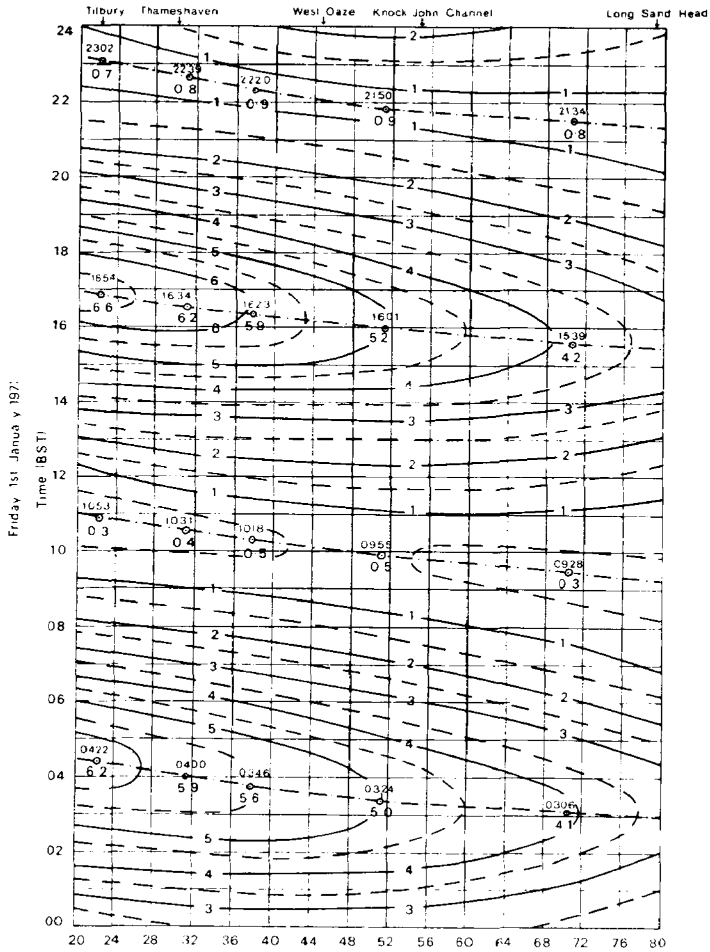

FIG. 5a. — Distance in Sea Miles (from London Bridge).
Predicted tidal heights (metres).

feet (2.4 metres) above prediction — or lower it an equivalent amount below. Such large amplitudes are rare, but surges of ± 4 feet (1.2 metre) occur one or twice a year and ± 2 feet (0.6 metre) are not uncommon.

6. THE FUTURE

The Port of London Authority is considering the deepening of the approaches to the port so that the deepest draught vessels will have access to a possible new development in the Maplin Sands area (see figure 1). If this were to be so then a very much greater length of the approach channel would be at critical depths and the need for accurate and up-to-date hydrographic and tidal information will be accentuated.

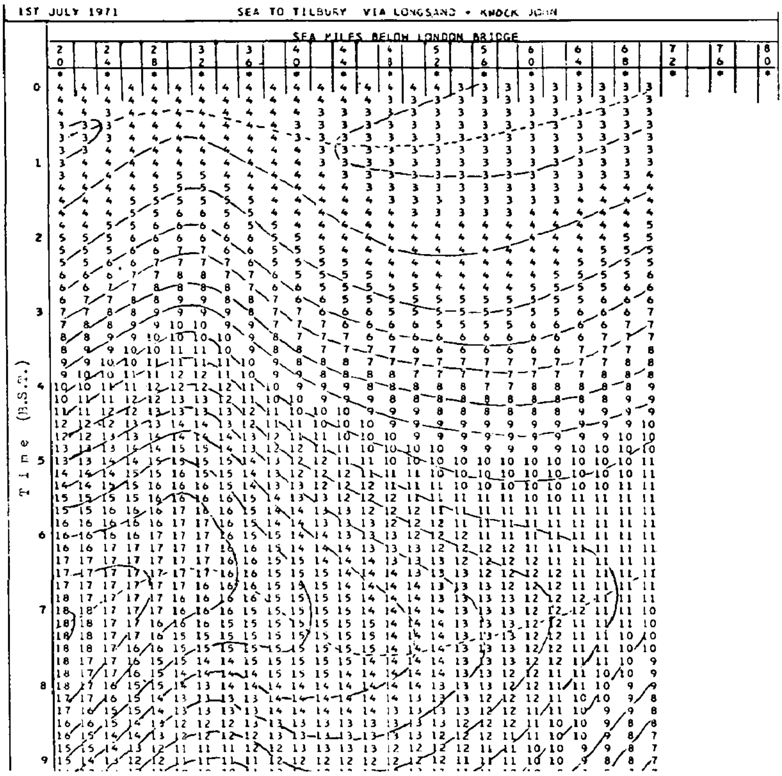

FIG. 5b. — Photo-reduction of part of a computer print-out of tidal predictions along the principal entry route to the Port of London.
Distances, expressed in sea miles from London Bridge, are shown along the top of the tabulation at intervals of 4 sea miles. Time is shown down the left hand side at intervals of one hour. Thus, predictions are shown as heights in feet above chart datum every 2 miles along the channel at intervals of ten minutes. Contours of equal predicted height and the lines of High Water and Low Water have been drawn in by hand.

This need will have to be fulfilled by a greater output of soundings from the survey craft, possibly using depth measuring sonar and definitely using computer processing of the field survey data to operate automatic plotting machines.

An accurate, portable and reliable recording tide gauge, probably equipped with a radio output direct to the survey craft, will be needed, and the Authority may have to install another permanent recording tide gauge offshore at the seaward end of the approach channel.

The problem of giving up-to-date forecasts of the expected differences between predicted and actual tides must also be met : this is obviously important when the storm surge has a negative value. The setting up of a Negative Surge Warning system for the southern North Sea must be considered; such a system might well run in parallel with the present Storm Tide Warning Service which exists to give warning of possible flooding resulting from positive surges.

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